Department of Zoology and Botany.

Mr. J. Gwyn Jeffreys, F.R.S., gave an account of the biological results of the voyage of the *Valorous* to Disco Island in 1875, which will be published in full in the *Proceedings* of the Royal Society. He urged the importance of repeated expeditions of this kind. A century of hard work would not suffice to collect all the information that was needed. Hitherto naturalists had only scraped the bottom of a few acres out of the many millions of square miles of the ocean. The British nation had hitherto done very little for submarine discovery in proportion to the poorer countries of Scandinavia, which had sent out expedition after expedition, yielding the most valuable results to science. Unfortunately, the latest intelligence as to the present Norwegian enterprise was that their work had been much interfered with by tempestuous weather. An important result of Mr. Jeffreys' experience was the bringing up of large and small stones, some very sharp, from the sea-bottom, at great depths. He thought telegraphic engineers had not taken this sufficiently into account in the construction of cables, having proceeded as if they had only to deal with an entirely soft bottom. The number of species of mollusca obtained by the *Valorous* was 183, of which forty were new to science. His opinion, derived from personal knowledge of the American, as well as of the European, fauna, was that the submarine fauna of Davis' Straits was predominantly European, although a number of American forms were found with them. An interesting feature was the discovery of a number of species previously only known in a fossil state in Tertiary rocks far distant, as in the Mediterranean; other species were remarkable because it was now for the first time shown what an enormous range in space and latitude they had, sometimes at least 1,200 miles. Dr. McIntosh, of St. Andrews, Prof. Dickie, of Aberdeen, and Dr. Carpenter gave addresses respectively on the Annelids, the Diatoms, and the Arenaceous Foraminifera brought home by the *Valorous*, and confirmed Mr. Gwyn Jeffreys in maintaining the predominance of European forms.

Mr. John Murray gave an address on oceanic deposits and their origin, based on observations on board the *Challenger*. He described and exhibited specimens of various kinds of deep-sea deposits. He did not think the detritus of the modern land was carried more than two or three hundred miles from the shore. A novel constituent of the deepest sea-bottoms was pumice dust, which had been found in almost every region, arising from submarine volcanic action. Mr. Murray thought he had never failed to find a piece of pumice, when it was carefully looked for in any of the dredgings, and he believed it to be the chief origin of the deep-sea clays. Another element which appeared to have been detected at great depths was "cosmic dust," or dust formed from aërolites. Another interesting point was that whenever they got into deep water, they found manganese peroxide in nodules inclosing organic remains—sharks' teeth and pieces of bone. This formation seemed to be connected with the disintegration of volcanic rocks. Mr. Murray also discussed the question whether true equivalents of the deep-sea deposits now made known were to be found in the series of stratified rocks. If this were not the case, then it must be held that the great continents had remained substantially the same throughout a vast length of time.

FORCE[1]

AT short notice it was not to be expected that I could produce a lecture which should commend itself to the Association by its novelty or originality. But in science there are things of greater value than even these—namely definiteness and accuracy. In fact without them there could not be any science except the very peculiar smattering which is usually (but I hope erroneously) called "popular." It is vain to expect that more than the elements of science can ever be made in the true sense of the word popular; but it is the people's *right* to demand of their teachers that the information given them shall be at least definite and accurate, so far as it goes. And as I think that a teacher of science cannot do a greater *wrong* to his audience than to mystify or confuse them about fundamental principles, so I conceive that wherever there appears to to be such confusion it is the *duty* of a scientific man to endeavour by all means in his power to remove it. Recent criticisms of works in which I have had at least a share, have shown me that, even among the particularly well-educated class who write for the higher literary and scientific journals, there is wide-spread ignorance as to some of the most important elementary principles of physics. I have therefore chosen, as the subject of my lecture to-night, a very elementary but much abused and misunderstood term, which meets us at every turn in our study of natural philosophy.

I may at once admit that I have nothing new to tell you, nothing which (had you all been properly taught, whether by books or by lectures) would not have been familiar to all of you. But if one has a right to judge of the general standard of popular scientific knowledge from the statements made in the average newspaper—or even from those made in some of the most pretentious among so-called scientific lectures—there can be but few people in this country who have an accurate knowledge of the proper scientific meaning of the little word Force.

We read constantly of the so-called "Physical Forces"—heat, light, electricity, &c.—of the "Correlation of the Physical Forces," of the "Persistence or Conservation of Force." To an accurate man of science all this is simply error and confusion, and I have full confidence that the inherent vitality of truth will render the attempt to force such confusion upon the non-scientific public quite as futile as the hopelessly ludicrous endeavour of the *Times* to make us spell the word chemistry with a Y instead of an E. It is true that in matters such as this last a good deal depends (as Sam Weller said) "on the taste and fancy of the speller"—and sometimes even absolute error is of little or no consequence. But it is quite another thing when we deal with the fundamental terms of a science. He who has not exactly caught their meaning, is pretty certain to pass from chronic mistakes to frequent blunders, and cannot possibly acquire a definite knowledge of the subject.

In popular language there is no particular objection to multiple meanings for the same word. The context usually shows exactly which of these is intended—and their existence is one of the most fertile sources of really good puns, such as those of Hood, Hook, or Barham. And there is no reason to object to such phrases as the *force of habit*, the *force of example*, the *force of circumstances*, or the *force of public opinion*. But when we read, as I did last week, in one newspaper, that the "force" of a projectile from the 81-ton gun has at last reached the extraordinary amount of 1,450 feet, in another that the "force" of a ball from the great Armstrong gun, lately made for the Italian government, is expected to average somewhere about 30,000 foot-tons—and in a third that the water in the boiler of the *Thunderer* "would in a second of time generate a 'force' sufficient to raise 2,000 tons one foot high"—we see that there must be, somewhere at least, if not everywhere, a most reckless abuse of language. In fact we have come to what ought to be scientific statements, and *there* even the slightest degree of unnecessary vagueness is altogether intolerable.

Perhaps no scientific English word has been so much abused as the word "force." We hear of "Accelerating Force," "Moving Force," "Centrifugal Force," "Living Force," "Projectile Force," "Centripetal Force," and what not. Yet, as William Hopkins, the greatest of Cambridge teachers, used to tell us—"Force is Force"—*i.e.*, there is but one idea denoted by the word, and all force is of one kind, whether it be due to gravity, magnetism, or electricity. This alone serves to give a preliminary hint that (as I shall presently endeavour to make clear to you) there is probably no such *thing* as force at all! That it is, in fact, merely a convenient expression for a certain "rate." If anyone should imagine that "3 per cent." is a sum of money, he will soon be grievously undeceived. "3 per cent." means nothing more nor less than the vulgar fraction $\frac{3}{100}$. True, the "*Three Per Cents*" usually means something very substantial—but there the term is not a scientific one. Think for a moment how utterly any one of you, supposed altogether ignorant of shipping, would be puzzled by such a newspaper heading as "*The White Star-Line*" or "*The Red Jacket-Clipper*." No doubt some of our scientific terms approach as near to slang as do these; but we are doing our best to get rid of them.

A good deal of the confusion about Force is due to Leibnitz and some of his associates and followers, who, whatever they may have been as mathematicians, were certainly grossly ignorant of some elementary parts of dynamics, insomuch that Leibnitz himself is known to have considered the fundamental system of the *Principia* to be erroneous, and to have devised another and different system of his own. This fact is carefully kept back now-a-days, but it *is* a fact, and (as I have just said) has had a great deal to do with the vagueness of the terms for *Force* and *Energy* in some modern languages. In fact, in their modern

[1] Evening lecture by Prof. Tait at the Glasgow meeting of the British Association, Sept. 8.

dress, the *Vis Viva*, *Vis Mortua*, and *Vis Acceleratrix* of that time have, in some of their Protean shapes, hooked themselves like Entozoa into the great majority of our text-books.

Before dealing more definitely with the proper meaning of the word "Force" I must briefly consider how we become acquainted with the physical world, and how consequently it is more than probable that some of our most profound impressions, if uninformed, are completely erroneous and misleading.

In dealing with physical science it is absolutely necessary to keep well in view the all-important principle that—

Nothing can be learned as to the physical world save by observation and experiment, or by mathematical deductions from data so obtained.

On such a text, volumes might be written; but they are unnecessary, for the student of physical science feels at each successive stage of his progress more and more profound conviction of its truth. He must receive it, at starting, as the unanimous conclusion of all who have in a legitimate manner made true physical science the subject of their study; and, as he gradually gains knowledge by this—*the only*—method, he will see more and more clearly the absolute impotence of all so-called metaphysics, or *à priori* reasoning, to help him to a single step in advance.

Man has been left entirely to himself as regards the acquirement of physical knowledge. But he has been gifted with various *senses* (without which he could not even know that the physical world exists) and with *reason* to enable him to control and understand their indications.

Reason, unaided by the senses, is totally helpless in such matters. The indications given by the senses, unless interpreted by reason, are utterly unmeaning. But when reason and the senses work harmoniously together, they open to us an absolutely illimitable prospect of mysteries to be explored. This is the test of true science—there is no resting-place—each real advance discloses so much that is new and easily accessible that the investigator has but scant time to co-ordinate and consolidate his knowledge before he has additional materials poured into his store.

To sight without reason, the universe appears to be filled with light—except, of course, in places surrounded by opaque bodies.

Reason, controlling the indications of sense, shows us that the sensation of light is our own property; and that what we understand by brightness, &c., does not exist outside our minds. It shows us also that the sensation of colour is purely subjective, the only difference possible between different so-called rays of light outside the eye being merely in the extent, form, and rapidity of the vibrations of the luminiferous medium.

To hearing, without reason, the air of a busy town seems to be filled with sounds. Reason, interpreting the indications of sense, tells us that if we could SEE the particles of air, we should observe among them simply a comparatively slow agitation of the nature of alternate compressions and dilatations superposed upon their rapid motions among one another. And our classification of sounds as to loudness, pitch, and quality, is merely the subjective correlative of what in the air-particles is objectively the amounts of compression, the rapidity of its alternations, and the greater or less complexity of the alternating motion.

A blow from a stick or a stone produces pain and a bruise; but the motion of the stick or stone before it reached the body is as different from the sensation produced by the blow as is the alternate compression and dilatation of the air from the sensation of sound, or the etherial wave-motion from the sensation of light.

Hence to speak, as the great majority even of "educated" people do, of what we ordinarily mean by light or sound, as existing outside ourselves, is as absurd as to speak of a swiftly-moving stick or stone as pain. But no inconvenience is occasioned if we announce the intention to use the terms light and sound for the objective phenomena, and to speak of their subjective effects as "luminous impressions" or "noise," as the case may be. In this case there is outside us energy of motion of every kind, but in the mind mere corresponding impressions of brightness and colour, noise or harmony, pain, &c., &c.

As another instance, it is obvious that we must be extremely cautious in our interpretation of the immediate evidence of our own senses as to heat.

Touch, in succession, various objects on the table. A paper-weight, especially if it be metallic, is usually cold to the touch; books, paper, and especially a woollen table-cover, comparatively warm. Test them, however, by means of a *thermometer*, not by the sense of touch, and in all probability you will find little or no difference in what we call their *temperatures*. In fact, any number of bodies of any kind shut up in an inclosure (within which there is no fire or other source of heat) all tend to acquire ultimately the same temperature. Why, then, do some feel cold, others warm to the touch?

The reason is simply this—the sense of touch does *not* inform us directly of temperature, but of *the rate at which our finger gains or loses heat*. As a rule bodies in a room are colder than the hand, and heat always tends to pass from a warmer to a colder body. Of a number of bodies, all equally colder than the hand, that one will seem coldest to the touch which is able *most rapidly* to convey away heat from the hand. The question, therefore, is one of *conduction of heat*. And to assure ourselves that it is so, reverse the process: *let us*, in fact, *try an experiment*, though an exceedingly simple one; for the essence of experiment is to modify the circumstances of a physical phenomenon so as to increase its value as a test. Put the paper-weight, the books, and the woollen table-cloth into an oven, and raise them all to one and the same temperature—considerably above that of the hand. The woollen cloth will still be comparatively cool to the touch, while the metal paper-weight may be much too hot to hold. The order of these bodies, as to warm and cold, in the popular sense, is in fact reversed; and this is so because the hand is now *receiving* heat from all the various bodies experimented on, and it receives most rapidly from those bodies which in their previous condition were capable of abstracting heat most rapidly. However it may be in the moral world, in the physical universe the giving and taking powers of one and the same body are strictly correlative and equal.

Thus the direct indications of sense are in general utterly misleading as to the relative temperatures of different bodies.

In a baker's oven, at temperatures far above the boiling point of water (on one occasion even 320° F., so high indeed that a beef-steak was cooked in thirteen minutes), Tillet in France, and Blagden and Chantrey in England, remained for nearly an hour in comparative comfort. But though their clothes gave them no great inconvenience, they could not hold a metallic pencil-case without being severely burned.

On the other hand, great care has to be taken to cover with hemp, or wool, or other badly conducting substance, every piece of metal which has to be handled in the intense cold to which an Arctic expedition is subjected; for contact with very cold metal produces sores almost undistinguishable from burns, though due to a directly opposite cause. Both of these phenomena, however, ultimately depend on the comparative facility with which heat is conducted by metals.

Even from the instance just given, you cannot fail to see that there is a profound distinction between heat and temperature. Heat, whatever it may be, is SOMETHING which can be transferred from one portion of matter to another; the consideration of temperatures is virtually that of the mere CONDITIONS which determine whether or not there shall be a transfer of heat, and in which direction the transfer is to take place. Bear this carefully in mind, because it has most important analogies to the results we meet with in considering the nature of Force.

It has been definitely established by modern science that *heat, though not material, has objective existence in as complete a sense as matter has.*

This may appear, at first sight, paradoxical; but we must remember that so-called paradoxes are merely facts as yet unexplained, and therefore still apparently inconsistent with others already understood in their full significance.

When we say that matter has objective existence, we mean that it is something which exists altogether independently of the senses and brain-processes by which alone we are informed of its presence. An exact or adequate conception of it, if it could be formed, would probably be something very different from any conception which our senses will ever enable us to form; but the object of all pure physical science is to endeavour to grasp more and more perfectly the nature and laws of the external world, using the imperfect means which are at our command—reason acting as interpreter as well as judge, while the senses are merely more or less untrustworthy and incompetent witnesses, but still of inconceivable value to us because they are our only available ones.

Without further discussion we may state once for all that our conviction of the objective reality of matter is based mainly upon the fact, *discovered solely by experiment*, that we cannot in the slightest degree alter its quantity. We cannot destroy, nor can we produce, even the smallest portion of matter. But reason

requires us to be consistent in our logic; and thus, if we find anything else in the physical world whose quantity we cannot alter, we are bound to admit it to have objective reality as truly as matter has, however strongly our senses may predispose us against the concession. Heat therefore, as well as light, sound, electricity, &c., though not forms of matter, must be looked upon as being as real as matter, simply because they have been found to be forms of energy—which in all its constant mutations satisfies the test which we adopt as conclusive of the reality of matter. We shall find that this test fails when applied to force.

But you must again be most carefully warned to distinguish between heat and the mere sensation of warmth; just as you distinguish between the motion of a cudgel and the pain produced by the blow. The one is the *thing* to be measured, the other is only the more or less imperfect reading or indication given by the instrument with which we attempt to measure it in terms of some one of its effects. So that when your muscular sense impresses on you the notion that you are exerting force as in pushing or pulling, you ought to be very cautious in forming a judgment as to what is really going on; and you ought to demand much farther evidence before admitting the objective reality of force.

Until all physical science is reduced to the deduction of the innumerable mathematical consequences of a few known and simple laws, it will be impossible altogether to avoid some confusion and repetition, whatever be the arrangement of its various parts which we adopt in bringing them before a beginner. But when we confine ourselves to one definite branch of the subject, all of whose fundamental laws can be distinctly formulated, there need be no such confusion. Here in fact the mathematician has it all in his own hands. He is the skilled artificer with his plan and his trowel, and the hodmen have handed up to him all the requisite bricks and mortar.

[Prof. Tait then gives a quotation in support of this view.]

Whether there is such a *thing* as force or not I shall consider presently. But in the meanwhile there can be no doubt that it is a convenient term, provided it be employed in one definite sense, and one only. Let us then first see how it is to be correctly used. Here we cannot but consult Newton. The sense in which he uses the word "force," and therefore the sense in which we must continue to use it if we desire to avoid intellectual confusion, will appear clearly from a brief consideration of his simple statement of the laws of motion.

The first of these laws is: *Every body continues in its state of rest or of uniform motion in a straight line, except in so far as it is compelled by impressed forces to change that state.*

In other words, any change, whether in the *direction* or in the *rate* of motion of a body is attributed to *force*. Thus a stone let fall moves quicker and quicker, and we say that a force (viz., the weight of the stone, or the earth's attraction for it) is continually acting so as to increase the *rate* of the motion. If the stone be thrown upwards, the *rate* of its motion continually diminishes, and we say that the same force (the stone's weight) is continually acting so as to produce this diminution of speed. So far, none of you probably feels the least difficulty. But we have got only half of the information on this point which Newton's first law affords. You see the moon revolving about the earth, and the earth and other planets revolving about the sun—approximately, at least, in circles. Why is this? Their *directions* of motion are constantly changing; in fact, a curved line is merely a line whose direction changes from point to point, while a straight line is one whose direction does not change; but to produce this change of direction force is required just as much as to produce change of speed. That is supplied by the gravitation attraction of the central body of the system. The old notion was that a centripetal force was required to balance the so-called centrifugal force, it being imagined that a body moving in a circle had a tendency to fly outwards from the centre! Newton's simple law exposes fully the absurdity of this. If a body is to be made to move in a curved line instead of its natural straight path, you must apply force to compel it to do so; certainly not to prevent it from flying outwards from the centre, about which it is for the moment revolving. In fact, inertia means, not revolutionary activity, but dogged perseverance, and just as you must apply force *in* the direction of motion to change the *rate* of motion, so must you apply force *perpendicular* to the direction of motion to change that *direction.*

Newton's second law is now required: *Change of motion is proportional to the impressed force, and takes place in the direction of the straight line in which the force acts.*

Mark here most carefully that this one simple law holds for *all* kinds of force alike. There is no special law for gravitation-force and others for electric and magnetic forces. All are defined alike, without reference to their origin.

Motion, as Newton has previously defined it, is here used as a technical scientific term for what we now call *momentum*. It is the product of the mass moving into the velocity with which it moves. "Change of motion," therefore, is change of momentum, or the product of the mass of the moving body into its change of velocity. Now a change of velocity is itself a velocity, as we see by the science of mere motion—kinematics—the purely mathematical science of mixed space and time.

Newton's words, however, imply more than this. Of course, the longer a given force acts, the greater will be the change of momentum which it produces; so that to compare forces, which is the essence of the process of measuring them, we must give them equal times to act—or, in scientific language, we must measure a force by the *rate* at which it produces change of momentum. Rate of change of velocity is called in kinematics acceleration. Thus the measure of a force is the product of the mass of the body moved into the acceleration which the force produces in it. This is the so-called *Vis motrix*, or "moving force" of the Cambridge text-books:—the so-called *Vis acceleratrix*, or "accelerating force," being really no force at all, but another name for the kinematical quantity acceleration which I have just defined.

Unit force is thus that force which, *whatever be its source*, produces unit momentum in unit of time. If we employ British units—unit of force is that which, in one second, gives to one pound of matter a velocity of one foot per second. Here you must carefully notice that a *pound* of matter is a certain *mass* or quantity of matter. When you buy a pound of tea, you buy a quantity of the matter called tea, equal in *mass* to the standard pound of platinum. The idea of weight does not enter primarily into the process. In fact, the use of an ordinary balance depends upon one clause of Newton's law of gravitation—which tells us that in any locality whatever, the weights of bodies are equal if their masses are equal. The weight of a pound of matter varies from place to place on the earth's surface—it depends on the attracting as well as the attracted body. The mass of a body is its own property. The earth's attraction for a body, or the weight of the body, is a force which produces in it in one second, a velocity which (in this latitude, and at the sea-level) is about 32·2 feet per second. So that, in Glasgow the weight of a pound —which we take as our standard of mass—is rather more than thirty-two units of force, or, what comes to the same thing, the British unit of force is about the former weight of a penny letter —half an ounce.

Some people are in the habit of confounding force with momentum. No one having sound ideas of even elementary mathematics could be guilty of this or any similar monstrosity. He would as soon, as Hopkins used to say, measure heights in acres, or arable land in cubic miles. But to show to a non-mathematician that it is really monstrous to confound force and momentum, it suffices to change the system of units employed in measuring them, when it will be found that, if numerically equal for any one system of units, they are necessarily rendered unequal by a mere change of the unit employed for time. Now two things which are really equal to one another must necessarily be expressed by the same numerical quantity *whatever* system of units be adopted. Let us try then unit of force and unit of momentum, as defined by pound, foot, second, units: and see what alterations a common change of these fundamental units will make in their numerical expression.

Unit momentum is that of one pound of matter moving with a velocity of one foot per second. Unit force is that force which, acting for one second, produces in unit of mass a velocity of one foot per second. In each of these statements you may put an ounce or a ton, instead of a pound, and an inch or a mile in place of a foot, and their relative value will not be altered. But suppose we take a minute instead of a second as the unit of time. One foot per second is sixty feet per minute—so this change of the time unit increases sixty-fold the nominal value of the momentum considered. But in the case of the force our statement would stand thus:—What we formerly called unit of force is that which, acting for one-sixtieth only of our new unit of time produces in a mass of one pound, sixty-fold the new unit of velocity. In other words the number expressing the momentum is increased sixty-fold, while that representing the force is increased three thousand six hundred fold.

In fact, whatever be the system of units you employ—if you increase in any proportion the unit of time, the measure of a

momentum is increased, in that proportion simply, while that of a force is increased in the duplicate ratio. The two things are, therefore, of quite dissimilar nature, and cannot lawfully be equated to one another under any circumstances whatever.

The mathematician expresses this distinction at once by saying that momentum is the time-integral of force, because force is the rate of change of momentum.

But what I have already said as to the meaning of Newton's two first laws leaves absolutely no doubt as to the only definite and correct meaning of the word force. It is obviously to be applied to any pull, push, pressure, tension, attraction, or repulsion, &c., whether applied by a stick or a string, a chain or a girder; or by means of an invisible medium such as that whose existence is made certain by the phenomena of light and radiant heat, and which has been shown with great probability to be capable of explaining the phenomena of electricity and magnetism.

I have already mentioned to you that the notion of force is suggested to us by the so-called muscular sense, which gives us a peculiar feeling of pressure when we attempt to move a piece of matter. To get a notion of what it really means we must again have recourse to physical facts instead of the uncontrolled evidence of the senses. Almost all that is required for this purpose is summed up for us in the remaining law of motion. Before we take it up, however, let us briefly consider the position at which we have arrived.

We have seen how to get rid of two gratuitous absurdities—the so-called centrifugal force and accelerating force, and we must proceed to exterminate living force. Cormoran and Blunderbore have been disposed of, but a more dangerous giant remains. More dangerous because he is a reality, not a phantom like the other two. Whatever force may be, there is no such thing as centrifugal force; and accelerating force is not a physical idea at all. But that which is denoted by the term living force, though it has absolutely no right to be called force, is something as real as matter itself. To understand its nature we must have recourse to another quotation from the *Principia*.

Newton's third law of motion is to the effect that—

"*To every action there is always an equal and contrary reaction; or, the mutual actions of any two bodies are always equal and oppositely directed.*"

This law Newton first shows to hold for ordinary pressures, tensions, attractions, impacts, &c., that is for *forces* exerted on one another by two bodies, or their time-integrals. And when he says—"If any one presses a stone with his finger his finger is pressed with an equal and opposite force by the stone," we begin to suspect that force is a mere name—a convenient abstraction—not an objective reality.

Pull one end of a long rope, the other being fixed. You can produce a practically *infinite* amount of force, for there is stress across every section throughout the whole length of the rope. Press upon a movable piston in the side of a vessel full of fluid. You produce a practically infinite amount of force—for across every ideal section of the liquid a pressure per square inch is produced equal to that which you applied to the piston. Let go the rope, or cease to press on the piston, and all this practically infinite amount of force is gone!

The only man who, to my knowledge, ever tried to discover experimentally what might be correctly called *conservation of force*, was Faraday. He was not satisfied with the mode of statement of Newton's law of gravitation, in which the mutual attraction between two bodies is said to VARY inversely as the square of their distance from one another. When the distance between two bodies is doubled, their mutual attraction falls off to one-fourth of what it formerly was. Faraday seriously set to work to determine what became of the three-fourths which have disappeared, but all his skill was insufficient to give him any result. Faraday's insight was so profound that we cannot assert that something may not yet be discovered by such experiments, but it will assuredly not be a conservation of force.

But Newton proceeds to point out that this third law is true in another and much higher sense. He says:—

"*If the action of an agent be measured by the product of its force into its velocity; and if, similarly, the reaction of the resistance be measured by the velocities of its several parts into their forces, whether these arise from friction, cohesion, weight, or acceleration, action and reaction, in all combinations of machines, will be equal and opposite.*"

The actions and reactions which are here stated to be equal and opposite, are no longer simple forces, but the *products* of forces into their velocities; *i.e.*, they are what are now called *rates of doing work*; the time-rate of increase, or the increase per second of a very tangible and real SOMETHING, for the measurement of which rate Watt introduced the practical unit of a *horse-power*, or the rate at which an agent works when it lifts 33,000 pounds 1 foot high per minute against the earth's attraction.

Now think of the difference between raising a hundredweight and endeavouring to raise a ton. With a moderate exertion you can raise the hundredweight a few feet, *and in its descent it might be employed to drive machinery, or to do some other species of work.* But tug as you please at the ton, you will not be able to lift it; and therefore, after all your exertion, it will not be capable of doing any work by descending again.

Thus it appears that *force* is a mere name, and that the *product of a force into the displacement of its point of application* has an objective existence. In fact, modern science shows us that force is merely a convenient term employed for the present (very usefully) to shorten what would otherwise be cumbrous expressions; but it is not to be regarded as a *thing*, any more than the bank *rate of interest* (be it 2, $2\frac{1}{2}$, or 3 per cent.) is to be looked upon as a sum of money, or than the birth-rate of a country is to be looked upon as the actual group of children born in a year. Another excellent instance is to be had from the rainfall. We say rain fell on such a day at the rate of an inch in twenty-four hours. What *can* be an inch of rain? especially when we mean a *linear*, not a *cubic* inch. But there is no confusion or absurdity here. What is implied is that, if it had gone on raining at that rate for twenty-four hours, and if the rain (like snow) remained where it fell, the ground would have been coated to the depth of an inch.

In fact, a simple mathematical operation shows us that it is precisely the same thing to say:—

The horse-power or amount of work done by an agent in each second is the product of the force into the average velocity of the agent,

and to say—

Force is the rate at which an agent does work per unit of length.

In the special illustration of Newton's words which I have just given, the resistance was a *weight*, that of a hundredweight or of a ton. When the resistance was overcome, work was done, and it was stored up for use in the raised mass—in a form which could be made use of at any future time.

Following a hint given by Young, we now employ the term ENERGY to signify the power of doing work, in *whatever* that power may consist. The raised mass, then, we say possesses, in virtue of its elevation, an amount of energy precisely equal to the work spent in raising it. This dormant, or passive, form is called *potential* energy. Excellent instances of potential energy are supplied by water at a high level, or with a "head," as it is technically called, in virtue of which it can in its descent drive machinery—by the wound-up "weights" of a clock, which in their descent keep it going for a week; by gunpowder, the chemical affinities of whose constituents are called into play by a spark, &c., &c.

Another example of it is suggested by the word "cohesion," employed in Newton's statement, and which must be taken to include what are called molecular forces in general, such as, for instance, those upon which the elasticity of a solid depends.

When we draw a bow, we do work, because the force exerted has a velocity; but the drawn bow (like the raised weight) has in potential energy the equivalent of the work so spent. That can in turn be expended upon the arrow; and *what then?*

Turn, again, to Newton's words, and we see that he speaks of one of the forms of resistance as arising from "acceleration." In fact the arrow, by its inertia, resists being set in motion; work has to be spent in propelling it, but the moving arrow has that work in store in virtue of its motion. It appears from Newton's previous statements that the measure of the rate at which work is spent in producing acceleration is *the product of the momentum into the acceleration in the direction of motion*, and the energy produced is measured by *half the product of the mass into the square of the velocity produced in it.* This active form is called *kinetic* energy, and it is the double of this to which the term *vis viva*, or *living force*, has been erroneously applied.

As instances of ordinary kinetic energy, or of mixed kinetic and potential energies, take the following:—A current of water capable of driving an undershot wheel; winds, which also are used for driving machinery; the energy of water-waves or of sound waves; the radiant energy which comes to us from the sun, whether it affect our nerves of touch or of sight (and there-

fore be called radiant heat or light) or produce chemical decomposition, as of carbonic acid and water in the leaves of plants, or of silver salts in photography (and be therefore called actinism); the energy of motion of the particles of a gas, upon which its pressure depends, &c. [When the motion is vibratory the energy is generally half potential, half kinetic.]

These explanations and definitions being premised, we can now translate Newton's words (without alteration of their meaning) into the language of modern science, as follows:—

Work done on any system of bodies (in Newton's statement the parts of any machine) *has its equivalent in work done against friction, molecular forces, or gravity, if there be no acceleration; but if there be acceleration, part of the work is expended in overcoming the resistance to acceleration, and the additional kinetic energy developed is equivalent to the work so spent.*

But we have just seen that when work is spent against molecular forces, as in drawing a bow or winding up a spring, it is stored up as potential energy. Also it is stored up in a similar form when done against gravity, as in raising a weight.

Hence it appears that, according to Newton, whenever work is spent it is stored up either as potential or as kinetic energy, except, possibly, in the case of work done against friction, about whose fate he gives us no information. Thus Newton expressly tells us that (except, possibly, when there is friction) *work is indestructible,* it is changed from one form of energy to another, and so on, but never altered in quantity. To make this beautiful statement complete, all that is requisite is to know *what becomes of work spent against friction.*

Here, of course, experiment is requisite. Newton, unfortunately, seems to have forgotten that savage men had long since been in the habit of making it whenever they wished to procure fire. The patient rubbing of two dry sticks together, or (still better) the drilling of a soft piece of wood with the slightly blunted point of a hard piece, is known to all tribes of savages as a means of setting both pieces of wood on fire. Here, then, heat is undoubtedly produced, *but it is produced by the expenditure of work.* In fact work done against friction has its equivalent in the heat produced. This Newton failed to see, and thus his grand generalisation was left, though on one point only, incomplete. The converse transformation, that of heat into work, dates back to the time of Hero at least. But the knowledge that a certain process will produce a certain result does not necessarily imply even a notion of the "why;" and Hero as little imagined that in his æolipile heat was *converted into work,* as do savages that work can be *converted into heat.*

But whenever any such conversion or transference takes place there is necessarily motion: and the mere rate of conversion or transference of energy per unit length of that motion is, in the present state of science, very conveniently called force. No confusion can arise from using such a word in such a sense. On the contrary, there is always a gain in clearness when compactness can lawfully be introduced.

Rumford and Davy, at the very end of last century, by totally different experimental processes, showed conclusively that the materiality of heat could not be maintained, and thus gave the means of completing Newton's statement which, still farther extended and generalised rather more than thirty years ago by the magnificent experimental work of Colding and Joule, now stands as one massive pillar of the fast-rising temple of science:—known as the law of the *conservation of energy.*

The conception of kinetic energy is a very simple one, at least when visible motion alone is involved. And from motion of visible masses to those motions of the particles of bodies whose energy we call heat, is by no means a very difficult mental transition. Mark, however, that heat is not the mere motions but the energy of these motions; a very different thing, for heat and kinetic energy in general are no more "*modes of motion*" than potential energy of every kind (including that of unfired gunpowder) is a "*mode of rest!*" In fact a "*mode of motion*" is, if the word motion be used in its ordinary sense, purely kinematical, not physical; and if motion be used in Newton's sense, it refers to momentum, not to energy.

The conception of potential energy, however, is not by any means so easy or direct. In fact, the apparently direct testimony of our muscular sense to the existence of force makes it at first much easier for us to conceive of force than of potential energy. *Why* two masses of matter possess potential energy when separated—in virtue of which they are conveniently said to attract one another—is still one of the most obscure problems in physics. I have not now time to enter on a discussion of the very ingenious idea of the ultramundane corpuscles, the outcome of the life-work of Le Sage, and the only even apparently hopeful attempt which has yet been made to explain the mechanism of gravitation. The most singular thing about it is that, if it be true, it will probably lead us to regard all kinds of energy as ultimately kinetic.

And a singular quasi-metaphysical argument may be raised on this point, of which I can give only the barest outline. The mutual convertibility of kinetic and potential energy shows that relations of equality (though not necessarily of identity) can exist between the two, and thus that their proper expressions involve the same fundamental units, and in the same way. Thus, as we have already seen that kinetic energy involves the unit of mass and the square of the linear unit directly, together with the square of the time unit inversely, the same must be the case with potential energy; and it seems very singular that potential energy should thus essentially involve the unit of time if it do not ultimately depend in some way on energy of motion.

[Prof. Tait then gives instances of the inaccurate use of the word Force.]

To conclude—In defence of accuracy, which is the *sine quâ non* of all science, we must be "zealous," as it were, even to "slaying." And, as all the power of the *Times* will not compel us to put a *y* instead of an *e* into the word chemist, so neither will the bad example of Germany and France, though recommended to us with all the authority which may be attributed to an ex-president of this Association, succeed in inducing us to attach two or more perfectly distinct and incompatible scientific meanings to that useful little word, "force," which Newton has once and for ever defined for us with his transcendent clearness of conception.

I have now only to ask your indulgence for the crudeness of this lecture. All I can say is that in preparing it, I have done my best, under circumstances of time, place, and surroundings, all alike unpropitious. But the chance of being able to back up, however imperfectly, my old friend, Dr. Andrews, in whose laboratory I first learned properly to use scientific apparatus, and whose sage counsel impressed upon me the paramount importance of scientific accuracy, and above all, of scientific honesty—such a chance was one which no surroundings (however unpropitious) could have induced me to forego.

NOTES

We have received the "Daily Programme of the Twenty-fifth Meeting of the American Association," held at Buffalo, August 23–30. It forms a pamphlet of about 100 pages, but appears to have been published daily during the meetings, and is quite a model of what such a programme should be. It is clearly printed on excellent paper, and has not the overcrowded appearance that the programme of the British Association often presents. At the last meeting a standing committee was appointed to superintend the selection of papers, and to this committee a short abstract must be sent before the title of a paper can be transmitted to the sectional committees. A list of accepted papers is given each day, and appended is the time each is supposed to occupy in reading. The work of each section for each day is indicated, and all the necessary information as to officers, regulations, &c., are given. A list is also given daily of the number of members "elected" and the number "registered," with their addresses. Altogether for this meeting these amount to 352, and the number of papers entered for reading is 147. At this meeting seventeen fellows were elected, consisting of some of the best known names in American science. The next meeting of the Association will be held at Nashville, Tenn., on the last Wednesday of August, 1877, the president-elect being Prof. Simon Newcomb, of Washington.

Prof. Huxley was present at the meeting of the American Association for the Advancement of Science, held at Buffalo. After stating that he was quite unprepared to occupy their attention, he said:—In England we have no adequate idea of the extent of your country, its enormous resources, the distances from centre to centre of population, and we least of all understand the great basis of character which sprung from the other side of the Atlantic. There has been some talk of the influence of your climate carrying you back to the North American type,